Boundary-scan testing (also known as IEEE Standard 1149.1) and its related specifications, has become the de facto standard for testing complex digital and mixed-signal circuit designs during manufacturing of printed-circuit-board assemblies (PCBAs). While conventional test approaches such as in-circuit-test (ICT) methods may encounter difficulties due to lack of access to parts of a PCBA for probing circuit nodes, boundary-scan methods succeed since they are treated as embedded test resources that are designed into the manufacturing of a PCBA from the start of the design and development of the product.

The acceptance and adoption of boundary-scan systems have grown and the level of automation of boundary-scan systems and their software have improved along with the quality of models based on boundary-scan-description-language (BSDL) provided by integrated-circuit (IC) suppliers.

What may not be well known: there is a wide range of uses and working environments for boundary-scan systems and applications which, if considered “holistically,” can deliver benefits throughout a tested product’s life cycle and not just within the manufacturing test process.

Product Life Cycle

As an electronic product moves through its life cycle, from development stage through prototyping to manufacturing and finally to service and support phases, responsibility for the product also migrates through the product’s manufacturing organization. At the points of transfer from one department or discipline to the next within a company, significant delays and disruptions can occur from a variety of issues.

Delays can result due to the use of different test methods and equipment by different departments and organizations within a company. Lack of correlation in the test methods and equipment can put stress on interdepartment communications. If problems are not rapidly understood and resolved, such vital aspects as time-to-market, repair turnaround times, and product quality and reliability quickly escalate beyond acceptable limits. Symptoms of problematic transfers include extra design cycles, long prototype debug intervals, and logistical difficulties with preprogrammed devices.

For example, extra design cycles, caused by poor test coordination and manufacturability, may involve multiple layout versions and prototyping runs before a design is deemed ready for production. Long prototyping debug intervals can be caused in part by the presence of manufacturing faults that obscure design issues.

Logistical difficulties with pre-
programmed devices, such as wrong or out-of-date configurations of devices placed on PCBs for assembly, can result in assembly delays. Delays can stem from problems in manufacturing fault clearing caused by poor test diagnostics and/or inaccurate documentation. In addition, delays can come from excessive time spent in troubleshooting PCBs and PCBs, due to defective boards making it through structural testing. Delays can result from mystery failures in highly accelerated stress screen (HASS) or highly accelerated life testing (HALT) environmental testing, such as failures at a temperature extreme that may not occur at room temperature. Delays can be added by lengthy repair times, due to support departments with poor test capabilities.

The Life Cycle Aspect

Boundary-scan methods can help resolve many of the manufacturing delay issues, bringing quality improvements with economic benefits. Boundary-scan technology is particularly effective if it is implemented on a corporate basis as a fundamental part of a firm’s test strategy.

Boundary-scan tools can help achieve design-for-testability (DFT) goals. Using these tools early in the product cycle can result in reduced time-to-market and improved product quality. A designer will know, prior to prototyping, the level of test coverage possible for the product. If the test coverage is inadequate, the design can be modified and the test coverage reevaluated, avoiding the delays that would result from subsequent additional process steps caused by inadequate testing. By adopting a policy in which the design phase must include DFT analysis that meets coverage requirements, an organization can avoid wasted layout spins and unnecessary prototype builds.

Boundary-scan tools can help test prototypes more efficiently. Unlike structural test methods such as in-circuit testing, boundary-scan testing requires minimal test fixturing. As a result, boundary-scan methods can be applied to small prototype runs for detection and rapid repair of structural faults.

Screening for structural faults enables the designer to properly focus on design issues during the critical prototype stage. Boundary-scan methods can even provide access to a large set of test points for electrical stimulus and sensing during the debug process, as well as a convenient means of rapidly programming (and re-programming) flash and logic circuit elements on a board during firmware verification. The ease of applying boundary-scan methods means that design revisions can be quickly incorporated in the test and programming routines. Boundary-scan tools can optimize structural testing and improve production test efficiency in several important ways.

Boundary-scan-based tests typically run at high speed (on the order of tens of seconds even for complex PCBs) and can yield pin-point diagnostics, allowing the simplification or elimination of fixturing for testing. The modular nature of boundary-scan methods allow them to be combined with many other structural test methods, such as in-circuit testing or flying probe testing, which may already be in use in the factory.

Trapping Defective PCBAs

Circuit boards with faults not detected by structural testing are said to “escape” to the functional test stage. These “escape” boards may be detected during functional testing but, at this stage, may not be easily corrected. An unfortunate, highly undesirable result of functional test failures that cannot be diagnosed and repaired is what is known in PCB/PCBA manufacturing as the “bone pile” of waste circuits.

Boundary-scan tools help minimize the bone-pile by assuring that no (or few) manufacturing defects escape to the functional testing stage. Using boundary-scan methods as a precursor to functional test reduces the amount of time needed to troubleshoot difficult-to-diagnose circuit boards. Because of the precise diagnostic details provided by boundary-scan tools, circuit boards can be repaired with a single action rather than several procedures or actions. This precision will have a significant positive impact on product reliability and reduction of time-to-market.

The same tools used for boundary-scan testing can also perform high-throughput, in-system programming (ISP) of flash memory devices, programmable logic devices (PLDs), and devices with embedded memory (such as microcontrollers).

Programming is performed following board assembly at the optimal point in the manufacturing flow, and reprogramming can be performed easily without having to remove devices from a PCB or PCBA. In addition to saving time, economic benefits result from reducing the number of tools, avoidance of IC sockets, and simplifying the process flow.

Improved Stress Testing

Boundary-scan tools can significantly improve the effectiveness of environmental stress testing, such as HASS or HALT stress testing. Because the boundary-scan interface to the target is implemented over a thin cable which is highly impervious to interference, the test setup is straightforward.

Furthermore, boundary-scan testing can be set to run continuously so that environmentally induced failures will be detected and fault data collected and time-stamped for later diagnosis. Intermittent faults which might occur only at elevated temperatures, for example, are recorded, avoiding “no-trouble-found” situations and preventing the escape of products to the functional test step or, worse, to the field and the customer.

Integrating boundary-scan and functional-testing methods within one platform can provide major benefits to a manufacturing enterprise. Savings result from reduced product handling; fewer test stations, less floor space, a reduction in training requirements, and use of a familiar, unified graphical user interface (GUI) to the operator.

Boundary-scan technology can also be considered for system-level application for both test and in-system programming. This can be performed with either an external tester or embedded boundary-scan architecture. In both cases, control of the system-level applications can be conducted remotely.

Commercial ICs and software are available that enable such boundary-scan control to be designed into a target system, which can then execute applications without need for external control. This integrated architecture approach can be employed to advantage in maintaining test and programming access to in-service systems.

Boundary-scan test methods can be effective in repair operations. Centralized as well as distributed repair facilities can use the same boundary-scan-based tests as the factory, helping to avoid correlation problems in analyzing test results. Furthermore, because boundary-scan requires almost no custom test setups, the repair department can rapidly switch between target types and versions in high-mix situations. In short, if a product has been well planned, including DFT, a manufacturer can greatly benefit from the use of boundary-scan methods. Transitions of responsibility from one organization to the next are streamlined, interdepartmental communication is
enhanced, and correlation problems are avoided by the use of a common test methodology.

**Functional Testing**

Integrating boundary-scan methods with functional test methods can enhance a product life cycle. Both test methods fulfill the necessary quality assurance steps for the anticipated fault spectrum. Boundary-scan testing is well suited for identifying manufacturing faults, typically caused by soldering problems, while functional testing is suitable for at-speed problems, such as faults that are manifested at operating range limits, user-generated errors, etc. These are the types of faults anticipated in actual use of a product.

Boundary-scan and functional testing can be combined with great effectiveness using a number of test system control interfaces, such as PCI, USB, Ethernet, LXI, or PXI(e) architectures. Recently, an alternative approach, known as JTAG Functional Test (JFT), provides JTAG/boundary-scan access to digital and mixed-signal circuit elements by means of a Python code program. The use of JFT enables a “boundary-scan only” solution to testing devices such as analog-to-digital converters (ADCs), digital-to-analog converters (DACs), or complex logic clusters that rely on conditional branching decisions. Scripts can also be further enhanced by adding (processor) core emulation test capabilities with CoreCommander functions.

In this scenario, boundary-scan vectors for testing, JFT scripts and ISP of PLDs and flash memory device, developed for use in the prior prototyping phase, are ported to the production environment and are driven to the circuit board by means of the chosen boundary-scan instrument in the functional test chassis.

Boundary-scan operations can be integrated into many functional test environments, such as custom GUIs or industry-standard test software tools (TestStand, LabVIEW, and others). The controller drives the vectors to the target and collects the results. If failures have been detected, they are analyzed with the same diagnostic routines available to the designer. JTAG/boundary-scan ISP applications can then be executed to “breathe life” into the target prior to the next test phase.

**Software to the Next Step**

Once the boundary-scan applications have run, and assuming they have run satisfactorily, the test management software proceeds to the next steps in a pre-programmed sequence.

For example, the test sequence may include a set of functional tests, such as temperature profiling, parametric measurements, electromechanical verification, etc. If the boundary-scan tests detect failures, then scan diagnostics and possibly visualization tools will direct a repair to the point(s) of failure. If in-system programming only is also required, these steps can be performed following structural testing.

There are a number of advantages to be derived from combining boundary-scan and functional testing within a test system, including a reduction in the number of process steps and a simplified product flow: a single stop for structural and functional testing with efficient in-system programming; a saving of factory floor space through the integration; and reduced training requirements for test personnel by using a uniform user interface.

**Compact Footprint**

Boundary-scan offers a compact footprint, high performance, and broad availability of instrument types, including compact modular PXI(e)-based boundary-scan instruments. Typical boundary-scan instruments allow as many as four individual targets to be tested and programmed. For high-volume production requirements, multiple boundary-scan controllers can be deployed, all running from a common test/programming source.

Testing is too often considered a part of manufacturing with no value-added component. However, this viewpoint ignores the real and substantial savings that can be realized with a well-conceived manufacturing test strategy. The test strategist should consider the life-cycle issues described here in which measurable cost savings can be achieved by use of boundary-scan, and which can be enhanced by combination with functional test.

**Contact:** JTAG Technologies, 111 N. West St., Suite A, Easton, MD 21601 ☎ 877-367-5824 or 410-770-4415
fax: 410-770-4774 E-mail: info@jtag.com Web: www.jtag.com